Optimal Control of Algae Biofilm Growth in Wastewater Treatment using Computational Mathematical Models

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Background

Utah State University (USU) is collaborating with the Central Valley Water Reclamation Facility (CVWRF), the largest water treatment plant in Utah (60 MGD), and WesTech-Inc. to innovate ways to reduce nitrogen and phosphorus levels in wastewater before being discharged into receiving waters. By 2018, in the state of Utah, there were 25 major sites of algal blooms that were primarily caused by excess nutrients [1]. The Rotating Algae Biofilm Reactor (RABR) provides an innovative way of removing nutrients from wastewater. Compared to standard raceway ponds, the RABR increases biofilm productivity up to 300%. No refereed literature exists on mathematically connecting RABR biofilm productivity with actual data.

Research Goals and Significance

The purpose of this research is to formulate a model of the mass production of the RABR as a function of sunlight, peripheral velocity, and rate of exposure.

- Develop a mathematical model to accurately predict biofilm growth
- Formulate a model of mass production of biofilm microalgae using the RABR as a function of light intensity, light exposure, and period

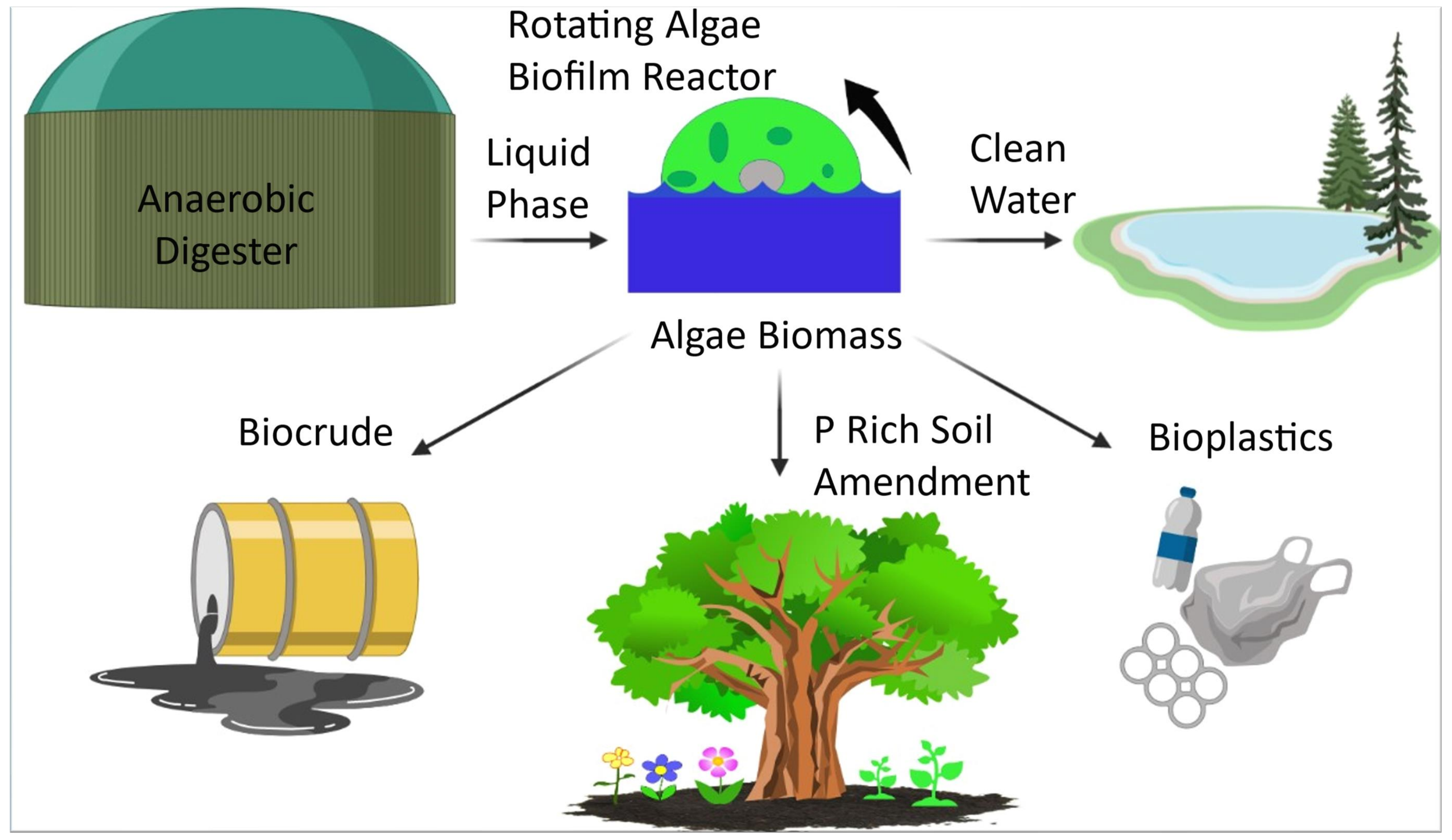

Figure 1: While treating wastewater, the biofilm harvested from the RABR also has significant potential for bioproducts such as biofuel, fertilizer, medicine, bioplastics, and livestock feed [2].

Methodology

Inspired by Lamare, we propose a computational mathematical model to discover the underlying mechanics of algae biofilm growth in wastewater treatment [4]. From [5], we propose the dynamics of the microalgae biofilm photosystems to be a system of ODEs:

$$\frac{dA}{dt} = -\sigma I A + \frac{B}{\tau} + k_r C,$$
$$\frac{dB}{dt} = \sigma I A - \frac{B}{\tau} - k_d \sigma I B,$$
$$\frac{dC}{dt} = -k_r C + k_d \sigma I B.$$

A:	(1)	*Proportion of cell photosystem that is ready for harvest*
B:	(1)	*Proportion of cell photosystem processing sunlight*
C:	(1)	*Proportion of cell photosystem that is inhibited*
I:	$(m^{-2}\mu E s^{-1})$	*Sunlight intensity*
τ:	(s)	*Turnover time of the electron transfer chain in cell*
σ:	$(m^2\mu^{-1}E^{-1})$	*Optical absorption cross-section of phtosynthetic units*
k_r:	(s^{-1})	*Rate of recovery from photoinhibition*
k_d:	(1)	*Damage constant to photosystem*

From this system of ODEs, we deduce the following set of equations:

$$\begin{cases} \dfrac{\partial B(z,t)}{\partial t} = \sigma I(z,t) - \sigma I(z,t)C(z,t) - \left(\sigma I(z,t) + k_d \sigma I(z,t) + \dfrac{1}{\tau}\right)B(z,t), \quad z \in [0,h], \\ \dfrac{\partial C(z,t)}{\partial t} = -k_r C(z,t) + k_d \sigma I(z,t) B(z,t), \quad z \in [0,h], \\ \dfrac{dh(t)}{dt} = \displaystyle\int_0^h k \frac{B(z,t)}{\tau} dz - R h(t). \end{cases}$$

Unlike [4], when we deduce our model of the biofilm height, we do not assume of a rapid steady state of the dynamics of A.

Preliminary Results

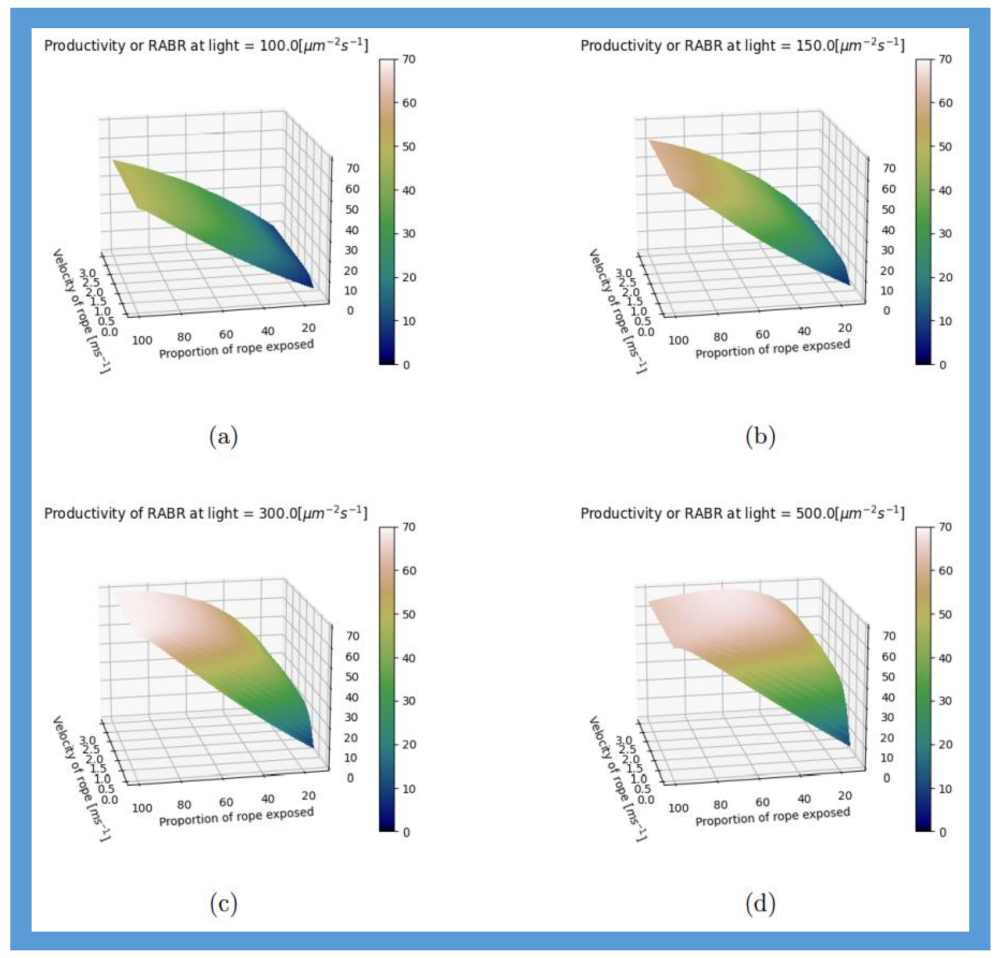

Figure 2: Algal biofilm productivity under varying light intensity situations. In this figure, the algal biofilm productivity over an eight-hour period are shown, under constant light intensity with I_0=100, 150, 300, 500, 1000, 2000 mu mol/m^2s.

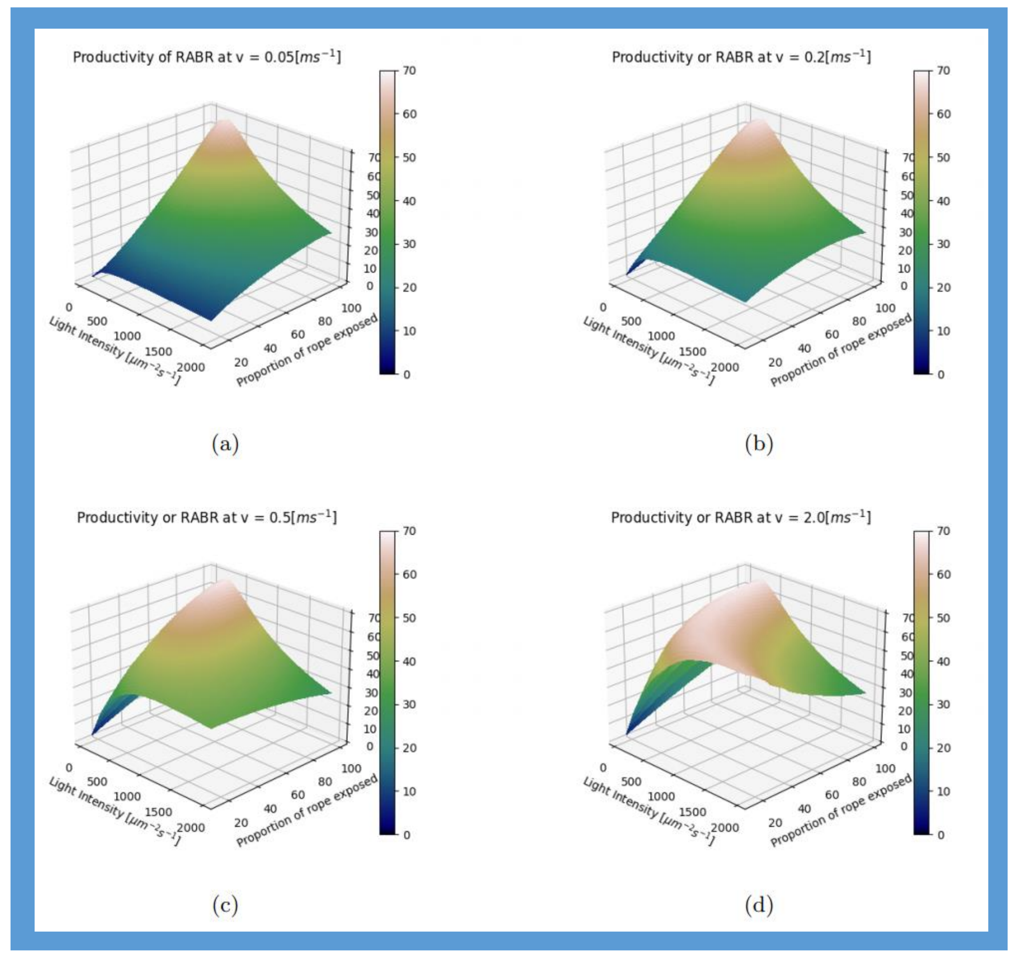

Figure 3: Algal biofilm productivity with various RABR peripheral velocities. Here the algal biofilm productivity are shown, with various RBAR peripheral velocity v=0.05 m/s, 0.2 m/s, 0.5 m/s, and 2 m/s.

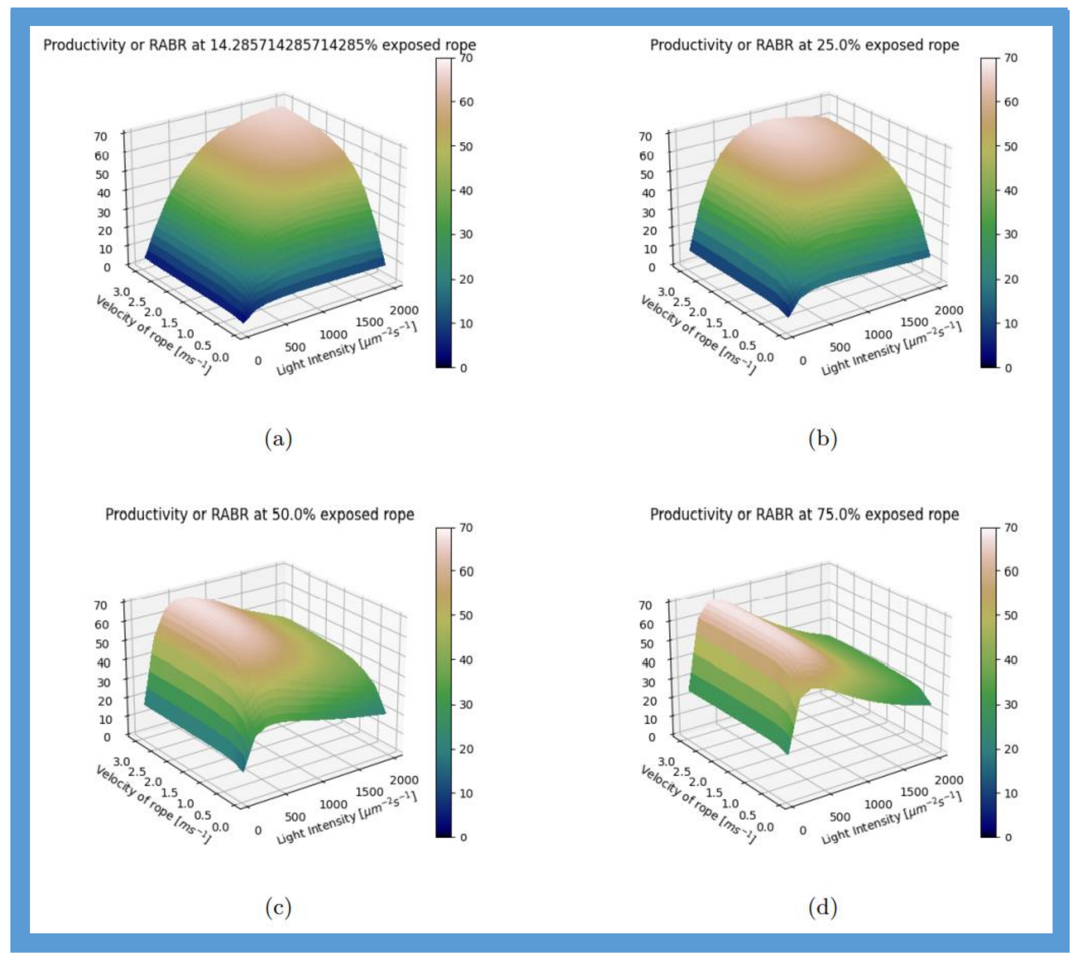

Figure 4: Algal biofilm productivity at various percentages of rope exposure. Here the biofilm productivity with light exposure percentage N = 1/7, 1/4, 1/2, 3/4, are presented.

Future Research

- Incorporate other variables of biofilm growth such as mass transfer or temperature
- Assist the efforts of CVWRF, WesTech-Inc. , and the state of Utah in reducing nutrient pollution in discharged waters

References

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